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Techno-Economic Analysis of a Hybrid Pv/Wind/ Diesel System

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ABSTRACT

Hybrid renewable energy systems are increasingly being utilized to provide electricity in remote areas especially where the grid extensions is considered too expensive. This research presents the results of techno-economic analysis of hybrid system comprising of solar and wind energy for powering six selected area in each state in the south-south geopolitical zones of Nigeria. All the necessary modelling simulation and technical economic evaluation are carried out using the assessment software package HOMER (Hybrid Optimization model for Electric Renewable). Two best optimal systems configuration namely PV-diesel-battery and PV-wind-diesel-battery-systems are compared with the conventional stand-alone diesel generators (DG) systems. Finally the environmental benefit of hybrid systems over the conventional stand-alone diesel systems is described.

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Key words: Hybrid, Renewable, Solar, Optimization, Generator, Grid

INTRODUCTION

A sufficient energy supply is indispensable for sustainable techno-economic development of any under developed or developing or developed nation [1]. A Nation will continue to be under developed and retard growth beyond the subsistence level without an appreciable access to energy supply [2]. About sixteen percent of the global population which is estimated One billion two hundred people around the world mostly in small villages and towns in developing countries currently lack grid-based electricity services according to the World Energy Outlook**, (**WEO, 2016) [3]. Many more suffer from supply that is of poor quality. More than 95% of those living without electricity are in countries in sub-Saharan Africa and developing Asia, and they are predominantly in rural areas (around 80% of the world total) [4]. While still far from complete, progress in providing electrification in urban areas has outpaced that in rural areas two to one since 2000, (WEO, 2016) [3].

The Nigerian Association of Energy Economists (NAEE) has said that about 75 per cent of Nigeria's 170 million people still live without access to regular electricity supply [5]. NAEE said that despite statistics indicating that 45 per cent of the country's population is currently connected to the national grid [6]; regular supply is still restricted to just about 25 % of the population [1]. According to the association, most of the people with access to electricity are found within the urban areas of the country, thus leaving citizens in the rural areas with less access to electricity supply [2]. NAEE therefore raised concern on economic redundancy in these parts of the country, adding that despite the importance of energy to economic development, large proportions of Nigerians still lack access to electricity [7]. The National President of NAEE, Prof. WumiIledare, who briefed journalists in Abuja on the occasion of the '2015 World Energy Day', pointed out that energy has contributed greatly to the transformation of the world and has provided comfort to the human race[8]. Iledare however noted that the association was concerned that majority of Nigerians do not have access to energy, stressing that for those with some form of access, availability and quality still remain major issues to contend with [9]. Even the Forty-five percentage population connected to the grid, incessant power supply has always being the situation in most cities in Nigeria due to the poor power situation, thus making electric energy consumers to supplement grid connections with self-powered generation(through diesel/petrol electric generators). Other than grid unavailability, energy supply mix in Nigeria is dominated by fossils sources [10].

HOMER found to be the most widely used optimization tool for modeling the HPS in this work [5]. It is a sophisticated tool or computer model that facilitates design of stand-alone electric power systems and performs simulations to satisfy the given load demand using alternative technology options and resources availability [11]. HOMER simulates a HPS, based on the hourly time stepped load data profile and the average monthly weather data of the specific location over a period of one year [7].

EXPERIMENTAL METHOD

Fig 1 shows daily load profile for each month. Measured hourly load profiles are not available for the selected sites; load data were thus synthesized by specifying typical daily load profiles. Characteristics of the load categories are: Domestic load: For each household, the load is based on 4 energy efficient compact fluorescent lamps (20 W each), 2 ceiling fans (30 W each), 1 television (80 W) and 1 radio (10 W). The load demand is approximately 108kWh/day. Social infrastructure: This includes the demand for the primary health center, public primary school, community hall and shops. The load demand is approximately 15kWh/day

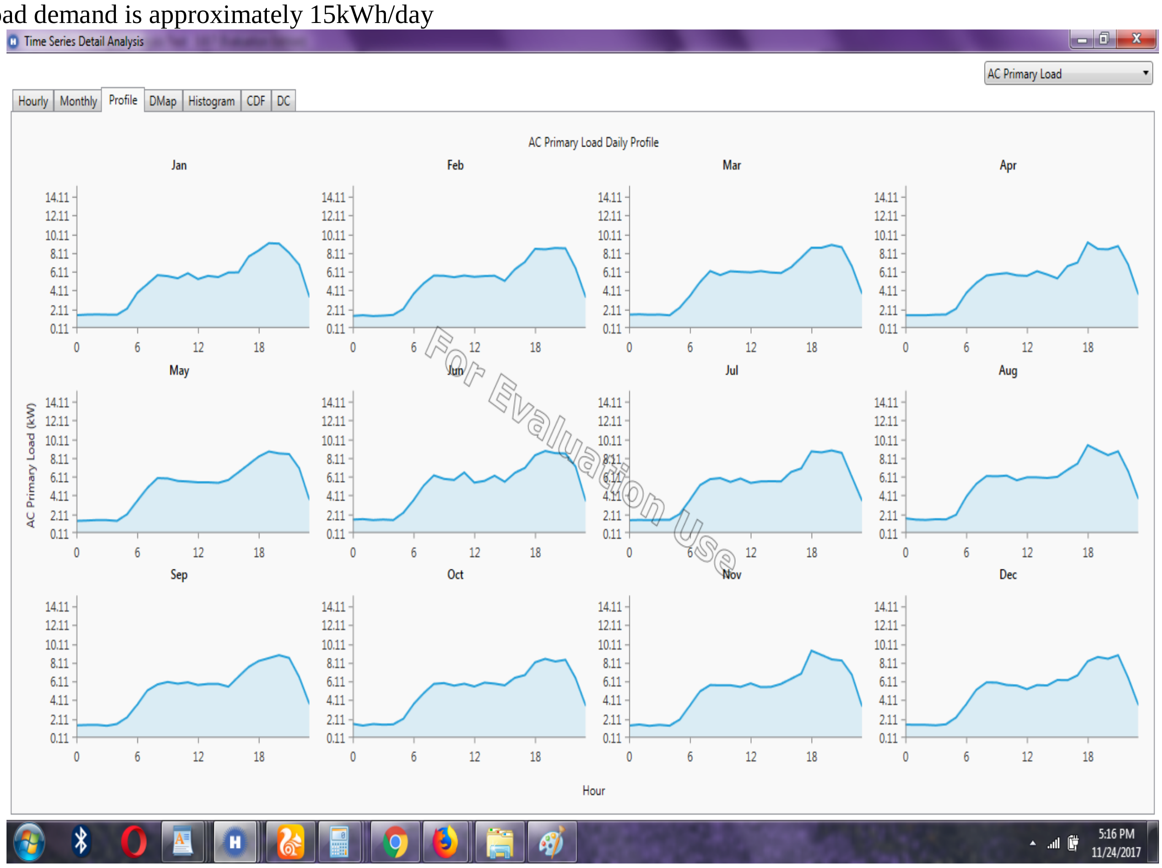


Fig. 1 Monthly AC primary load profile

Table -1 Estimated electricity demand for each rural community

Load	No in use	Power (watt)	January to December (hr/day)	(watt-hr/day)
Category A: Domestic load				
Lighting	4	20	8	640
Television	1	80	4	320
Radio	1	10	12	120
Ceiling fan	2	0	18	1080
Total for 50 household				108000
Category B: Social infrastructural Load				
• Primary health center				
Lighting (CFL)	6	20	10	1200
Refrigerator	1	600	16	9600
Television	1	80	6	480
Ceiling fan	2	30	12	720
Total				12000
• Public primary school				
Lighting (CFL)	7	20	4	560
Ceiling fan	1	30	6	180
Total				740

• Community hall and shops				
Lighting				
Ceiling fan	10	20	5	1000
Television	4	30	7	840
Total load	1	80	6	480
Miscellaneous load				2320
Total load consumption		80	6	480
				123540

Solar radiation

Table 2 shows the solar irradiation for each selected location as obtained from the Solar Electricity handbook global satellite database (www.solarelectricityhandbook.com/solar-irradiance.html), Using solar panel direction: East South East (67.5'). The solar radiation data for all six sites were obtained according to their respective latitude and longitude, as earlier presented in Table 1 and measured by precision pyrometer.

Table -2 Solar irradiation data for the six villages (kWh/m^2/day)

Month	**Village**					
	Iwofe	**Wilberforce island**	**Ikpa road**	**Okada**	**EdibeEdibe**	**Abraka**
January	5.14	5.19	5.47	5.37	5.55	5.27
February	5.18	5.19	5.53	5.43	5.59	5.27
March	4.74	4.82	5.25	5.28	5.28	5.12
April	4.53	4.78	5.02	4.99	5.02	4.98
May	4.16	4.31	4.65	4.67	4.71	4.48
June	3.48	3.53	4.24	4.16	4.29	3.69
July	3.19	3.22	3.79	3.51	3.83	3.25
August	3.37	3.45	3.71	3.51	3.63	3.76
September	3.63	3.54	4.22	4.33	4.27	4.21
October	3.63	3.54	4.22	4.33	4.27	4.21
November	4.16	4.33	4.79	4.94	4.79	4.92
December	4.90	4.97	5.23	5.19	5.27	5.08
Average	**4.176**	**4.239**	**4.677**	**4.643**	**4.708**	**4.520**

Wind speed

The monthly average wind speed data for an average of ten (10) years were obtained from Time and Date Weather global database (www.timeanddate.com/weather/nigeria) on the latitude and longitude of the different selected villages using anemometer at 10m above sea level. The annual average wind speed for each village is presented in Table 3. The wind speed from the selected site ranges from 2.9 to 6.9 m/s. The changes in the wind patterns occur as a result of earth's topography, bodies of water and vegetation cover. Observation of the wind probability and average monthly speed for a year, show that the peak wind speed occurs at 15.00hrs. The average wind speed of Iwofe village is shown in fig 2.

The wind turbine costing variables (initial cost, operation cost, and replacement cost) are similarly derived as for the PV array. Wind turbine operating costs comprise maintenance and replacement costs Maintenance costs for wind turbines can vary depending on the application, type of maintenance and wind turbine sizes. The wind turbine life is often assumed to be more than 20 years; therefore in many life cycle costing no wind turbine replacement will take place.

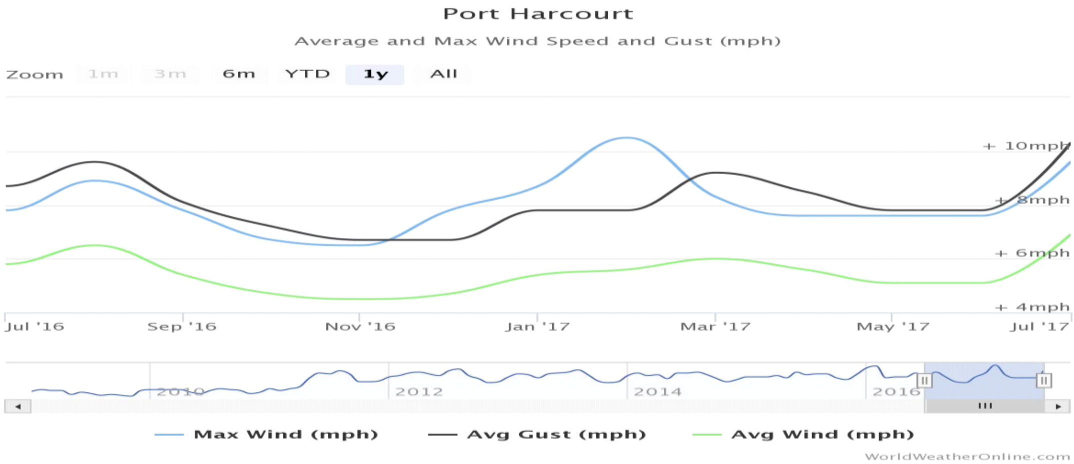


Fig. 2 Wind speed data for Iwofe village, Port Harcourt

Table -3 Wind speed data for the six villages

Month	Villages					
	Iwofe	**Wilberforce island**	**Ikpa road**	**Okada**	**EdibeEdibe**	**Abraka**
January	5.4	5.4	3.6	3.4	3.6	4.3
February	5.6	5.6	3.8	3.1	3.6	4.3
March	6.0	6.0	4.0	3.8	3.8	4.5
April	5.6	5.6	4.0	3.6	4.0	4.5
May	5.1	5.1	3.6	3.6	3.6	4.0
June	5.1	5.1	3.4	3.1	3.1	3.8
July	5.8	6.9	4.0	3.6	3.6	4.7
August	6.5	6.5	3.6	4.0	3.4	4.9
September	5.4	5.4	3.4	3.4	3.1	4.3
October	4.7	4.7	3.4	3.1	3.4	4.0
November	4.5	4.5	3.1	2.9	3.1	3.6
December	4.7	4.7	3.1	2.9	3.1	3.6
Average	**5.37**	**5.46**	**3.58**	**3.38**	**3.45**	**4.21**

Components Data

The proposed hybrid systems consist of PV panels, wind turbines, diesel generators and other system components such as batteries, converters. The PV panel, wind turbine and diesel generator combined to harness the overall system output as well as to compensate for the unpredictable variation in RE sources from one zone to another.. Assumptions regarding components pricing and sizing as adopted in the proposed hybrid system, are expressed below;

- The capital cost and replacement cost of 1W of PV array were taken as $3.0 and $2.0 respectively (Price from ebay store). The lifetime of PV arrays was taken as 20 years. The de-rating factor that accounts for losses due to temperature effects and dirts on the PV modules surface was assumed as 90%, and the ground reflection of the modules were taken as 20%. Different sizes of PV arrays were considered to get the optimal size for each village.
- A generic model wind turbine with rated capacity of 3 kW is considered. The initial cost of one unit is taken as $6000(Price from Amazon store). Replacement and operational maintenance costs were assumed as $4000 and $2000/ year respectively. In order to find an optimal size, different sizes of turbine options were analyzed. The operational lifetime of the turbine was considered as 20 years.
- The initial cost of AC diesel generator is $133/kW, with a replacement cost of $112/kW and maintenance cost of $0.500/hr. The operating lifetime of a diesel generator was taken as 15,000 h with 30% load ratio.
- A bi-directional converter is added to maintain the flow of energy between the alternating current (AC) and direct current (DC) components. It functions as a rectifier when it converts AC to DC, and as inverter on the other way round. The initial capital and replacement cost of the converter used in this study were taken as $1000/kW and $800/kW respectively. The operational and maintenance cost is assumed as $100/ year. The efficiency of the converter is assumed to be 90% that of rectifier is taken as 85% while the lifetime was taken as 10 years. Different sizes of converters were considered during the analysis.
- Generic 1Kwh lead acid type battery with rated 12 V nominal voltages and 1,156Ah capacity is considered in this study. The initial cost of one unit is $150. Replacement and operational maintenance costs were assumed as $110 and $50/ year respectively. In order to find an optimal configuration, the battery bank was assumed to contain different number of batteries. Each battery string contains 8 batteries and the lifetime energy of each battery is estimated as 9645 kWh throughput.
- 20 years Project lifetime is considered in the simulation and has operating reserve that accounts for sudden spikes in the system, Nominal discount rate of 10%, excepted inflation rate of 2% and hence unpredictable output.
- Maximum hourly load of 2% is considered as the capacity shortage factor (CSF); this shows the amount of time to which the system will not be able to meet the load requirement including its reserves.
- Controller initial cost of $ 250, Replacement of $160 and operational and maintenance cost of $40.
-

RESULTS AND DISCUSSION

HOMER performed an hourly time series simulation for every possible system configuration on a yearly basis in order to evaluate the operational characteristics such as annual electricity production, annual load served, excess electricity, renewable fraction and so on. The renewable energy sources and diesel load generator were evaluated in order to determine the feasibility of the system. HOMER searched for optimum system configuration and component sizes that meet the load requirement at the lowest Cost (NPC) and then presents the results of the simulation in term of optimal systems and sensitivity analysis. The optimal results are categorized based on tile sensitivity variables chosen. Table 5 shows the system architecture in terms of kW rating of the array, wind turbine, diesel generator and the converter. The number of batteries required for energy storage is also indicated under the system architecture. The conventional stand-alone diesel generator is presently employed in most rural areas in Nigeria, and hence considered as the base case simulation in this work. It is selected to allow a comparison to be made about the total savings that can be made by including a renewable energy source in the system design and implementation of hybrid power system (i.e comparing cost and emissions of DC with the proposed hybrid PV/wind/diesel/converter configuration). PV/diesel/battery/converter configuration is adjudged the optimal best in ikpa road, Abraka, EdibeEdibe, Okada and Wind/diesel/battery/converter configuration is adjudged the optimal best in Iwofe and Wilberforce island, and hence compared to the base case simulation with respect to NPC. RF, carbon emissions and diesel consumption for the diesel price ($0.56/ 1).

Total NPC calculations

The NPC of all the feasible system configurations considered for implementation of hybrid power system in the selected sites are illustrated in for diesel price of $0.56/ 1. NPC is calculated for the entire system based on the expected life of 20 years. The system configuration includes: Wind/ Diesel/ Battery/ converter, PV/ Wind/ Diesel/ Battery/ converter, Diesel/ Battery/ converter, PV/ Diesel/ Battery/ converter, PV/ Wind/ Battery/ converter, Diesel Standalone, Wind/ Diesel, PV/ Diesel/ converter, PV/ Wind/ Diesel/ converter, PV/ Battery/ converter, as results are shows in Table 4.

Table -4 NPC Simulation for all system Configuration

System Configuration	Iwofe	Wilberforce island	Ikpa road	Okada	EdibeEdibe	Abraka	AVG. NPC
Wind/Diesel/Battery/converter	461369	459127	525469	528556	529358	519966	503974.2
PV/Wind/Diesel/Battery/ converter	464248	464240	517604	519876	519033	507588	498764.8
Diesel/Battery/converter	510692	510692	510783	510783	510783	510588	510720.2
PV/Diesel/Battery/converter	513791	515055	502787	501767	502346	502576	506387
PV/Wind/Battery/converter	805118	767250	907906	915547	904874	886196	864481.8
Diesel	866926	866926	866926	866926	866926	866926	866926
Wind/Diesel	869541	869540	891667	891867	891816	890900	884221.8
PV/Diesel/converter	887894	888215	869537	869537	869537	869537	875709.5
PV/Wind/Diesel/converter	906534	906857	910273	910470	910420	909518	909012
PV/Battery/converter	1050000	1040000	898405	908390	893987	957751	958088.8
Wind/Battery/converter	1190000	1120000	N/A	N/A	N/A	2260000	-

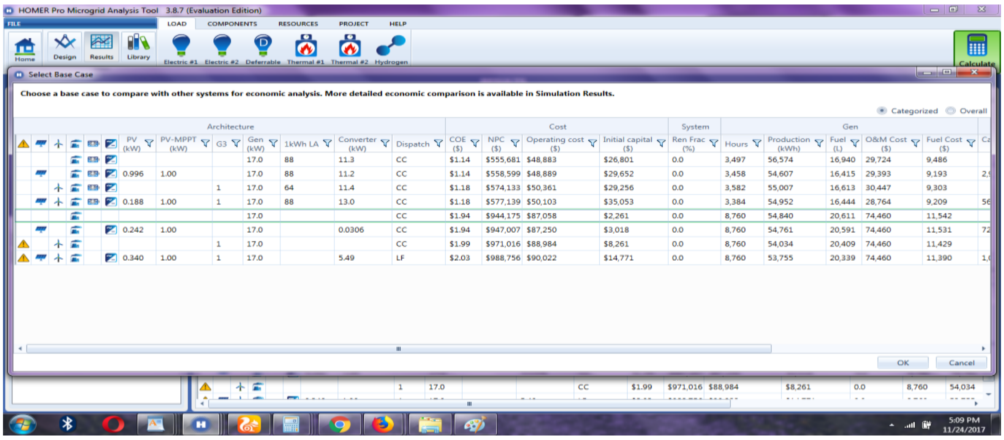


Fig. 3 NPC for diesel price of $0.56/1 for System configuration for ikpa road

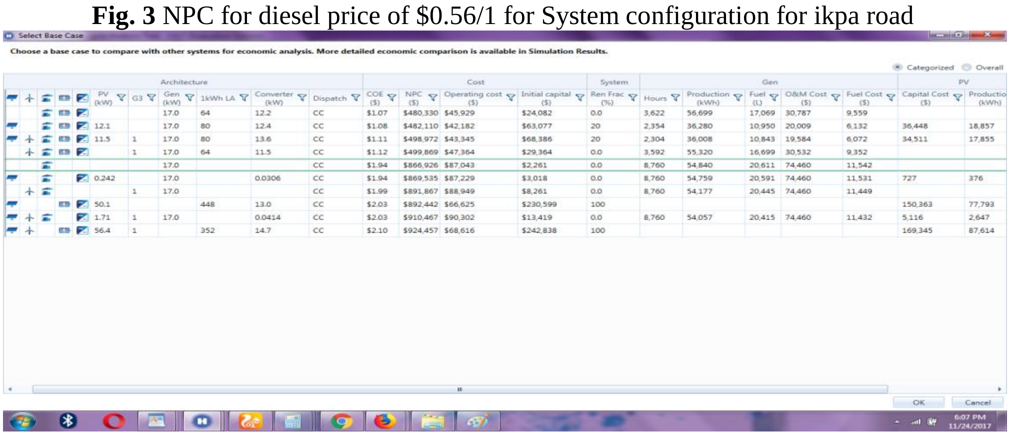
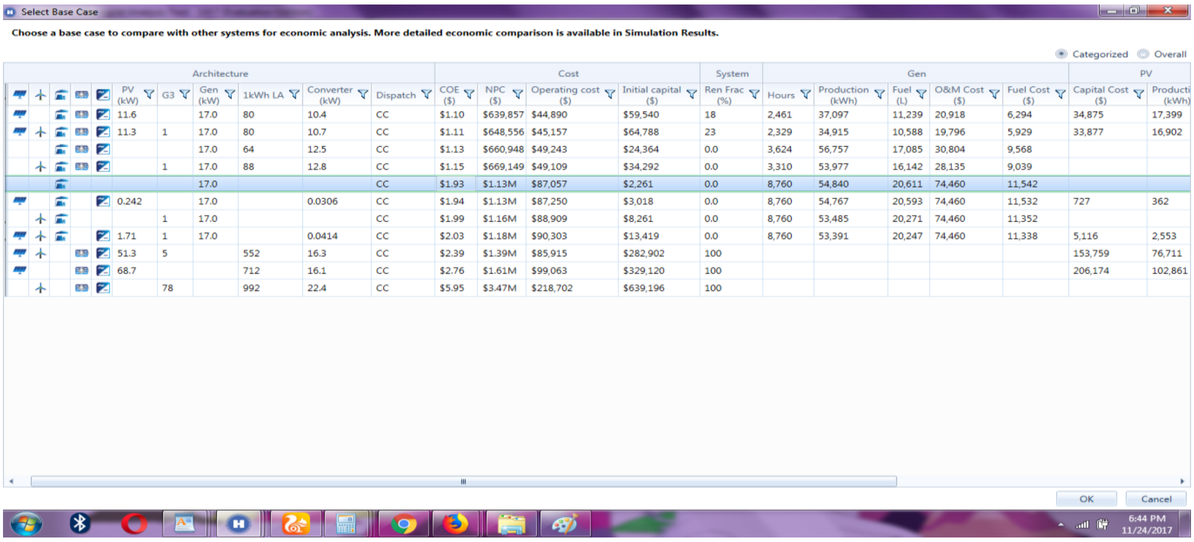
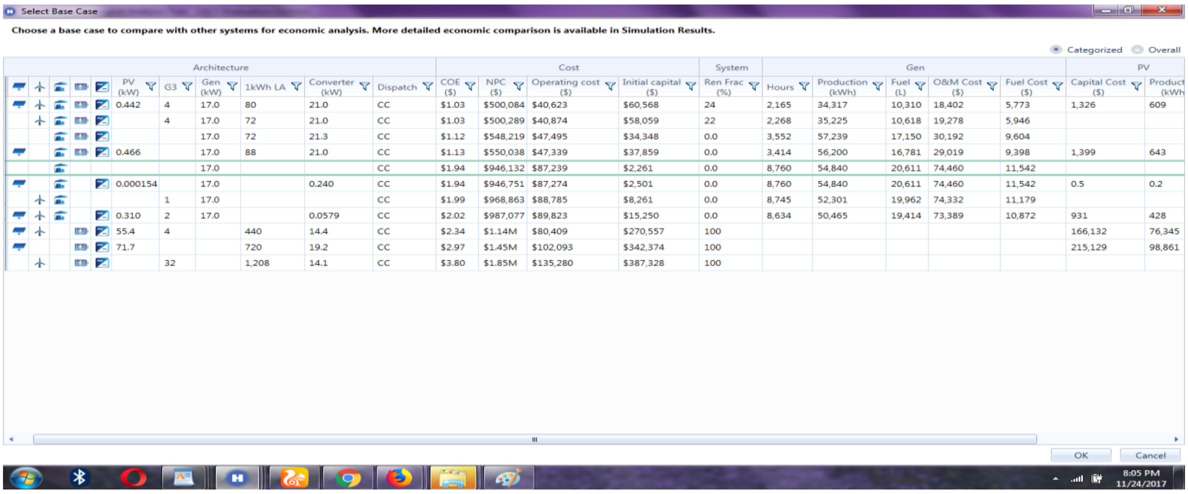


Fig. 4 NPC for diesel price of $0.56/1 for System configuration for Okada



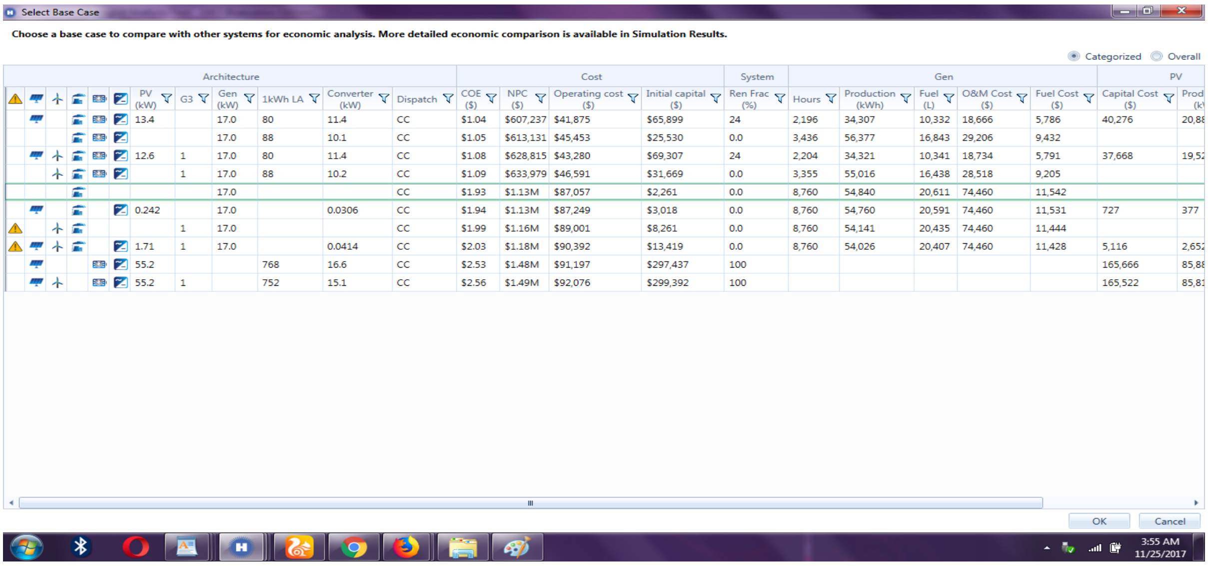
Architecture						Cost				System	Gen					PV	
PV (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Producti (kWh)
11.6		17.0	80	10.4	CC	$1.10	$639,857	$44,890	$59,540	18	2,461	37,097	11,239	20,918	6,294	34,875	17,399
11.3	1	17.0	80	10.7	CC	$1.11	$648,556	$45,157	$64,788	23	2,329	34,915	10,588	19,796	5,929	33,877	16,902
		17.0	64	12.5	CC	$1.13	$660,948	$49,243	$24,364	0.0	3,624	56,757	17,085	30,804	9,568		
	1	17.0	88	12.8	CC	$1.15	$669,149	$49,109	$34,292	0.0	3,310	53,977	16,142	28,135	9,039		
		17.0			CC	$1.93	$1.13M	$87,057	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242		17.0		0.0306	CC	$1.94	$1.13M	$87,250	$3,018	0.0	8,760	54,767	20,593	74,460	11,532	727	362
	1	17.0			CC	$1.99	$1.16M	$88,909	$8,261	0.0	8,760	53,485	20,271	74,460	11,352		
1.71	1	17.0		0.0414	CC	$2.03	$1.18M	$90,303	$13,419	0.0	8,760	53,391	20,247	74,460	11,338	5,116	2,553
51.3	5		552	16.3	CC	$2.39	$1.39M	$85,915	$282,902	100						153,759	76,711
68.7			712	16.1	CC	$2.76	$1.61M	$99,063	$329,120	100						206,174	102,861
	78		992	22.4	CC	$5.95	$3.47M	$218,702	$639,196	100							

Fig. 5 NPC for diesel price of $0.56/1 for System configuration for Abraka



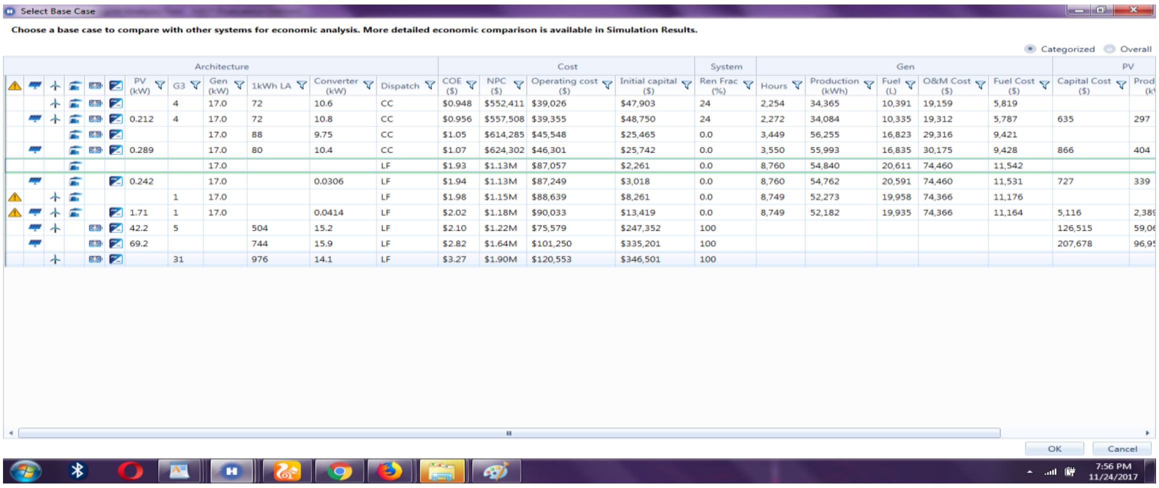
Architecture						Cost				System	Gen					PV	
PV (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Product (kWh
0.442	4	17.0	80	21.0	CC	$1.03	$500,084	$40,623	$60,568	24	2,165	34,317	10,310	18,402	5,773	1,326	609
	4	17.0	72	21.0	CC	$1.03	$500,289	$40,874	$58,059	22	2,268	35,225	10,618	19,278	5,946		
		17.0	72	21.3	CC	$1.12	$548,219	$47,495	$34,348	0.0	3,552	57,239	17,150	30,192	9,604		
0.466		17.0	88	21.0	CC	$1.13	$550,038	$47,339	$37,859	0.0	3,414	56,200	16,781	29,019	9,398	1,399	643
		17.0			CC	$1.94	$946,132	$87,239	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.000154		17.0		0.240	CC	$1.94	$946,751	$87,274	$2,501	0.0	8,760	54,840	20,611	74,460	11,542	0.5	0.2
	1	17.0			CC	$1.99	$968,863	$88,785	$8,261	0.0	8,745	52,301	19,962	74,332	11,179		
0.310	2	17.0		0.0579	CC	$2.02	$987,077	$89,823	$15,250	0.0	8,634	50,465	19,414	73,389	10,872	931	428
55.4	4		440	14.4	CC	$2.34	$1.14M	$80,409	$270,557	100						166,132	76,345
71.7			720	19.2	CC	$2.97	$1.45M	$102,093	$342,374	100						215,129	98,861
	32		1,208	14.1	CC	$3.80	$1.85M	$135,280	$387,328	100							

Fig. 6 NPC for diesel price of $0.56/1 for System configuration for iwofe



Architecture						Cost				System	Gen					PV	
PV (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Prod (k
13.4		17.0	80	11.4	CC	$1.04	$607,237	$41,875	$65,899	24	2,196	34,307	10,332	18,666	5,786	40,276	20,88
		17.0	88	10.1	CC	$1.05	$613,131	$45,453	$25,530	0.0	3,436	56,377	16,843	29,206	9,432		
12.6	1	17.0	80	11.4	CC	$1.08	$628,815	$43,280	$69,307	24	2,204	34,321	10,341	18,734	5,791	37,668	19,52
	1	17.0	88	10.2	CC	$1.09	$633,979	$46,591	$31,669	0.0	3,355	55,016	16,438	28,518	9,205		
		17.0			CC	$1.93	$1.13M	$87,057	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242		17.0		0.0306	CC	$1.94	$1.13M	$87,249	$3,018	0.0	8,760	54,760	20,591	74,460	11,531	727	377
	1	17.0			CC	$1.99	$1.16M	$89,001	$8,261	0.0	8,760	54,141	20,435	74,460	11,444		
1.71	1	17.0		0.0414	CC	$2.03	$1.18M	$90,392	$13,419	0.0	8,760	54,026	20,407	74,460	11,428	5,116	2,652
55.2			768	16.6	CC	$2.53	$1.48M	$91,197	$297,437	100						165,666	85,88
55.2	1		752	15.1	CC	$2.56	$1.49M	$92,076	$299,392	100						165,522	85,81

Fig. 7 NPC for diesel price of $0.56/1 for System configuration for EdibeEdibe



Select Base Case

Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

Categorized Overall

PV (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Prod (k
	4	17.0	72	10.6	CC	$0.948	$552,411	$39,026	$47,903	24	2,254	34,365	10,391	19,159	5,819		
0.212	4	17.0	72	10.8	CC	$0.956	$557,508	$39,355	$48,750	24	2,272	34,084	10,335	19,312	5,787	635	297
		17.0	88	9.75	CC	$1.05	$614,285	$45,548	$25,465	0.0	3,449	56,255	16,823	29,316	9,421		
0.289		17.0	80	10.4	CC	$1.07	$624,302	$46,301	$25,742	0.0	3,550	55,993	16,835	30,175	9,428	866	404
		17.0			LF	$1.93	$1.13M	$87,057	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242		17.0		0.0306	LF	$1.94	$1.13M	$87,249	$3,018	0.0	8,760	54,762	20,591	74,460	11,531	727	339
	1	17.0			LF	$1.98	$1.15M	$88,639	$8,261	0.0	8,749	52,273	19,958	74,366	11,176		
1.71	1	17.0		0.0414	LF	$2.02	$1.18M	$90,033	$13,419	0.0	8,749	52,182	19,935	74,366	11,164	5,116	2,38
42.2	5		504	15.2	LF	$2.10	$1.22M	$75,579	$247,352	100						126,515	59,0
69.2			744	15.9	LF	$2.82	$1.64M	$101,250	$335,201	100						207,678	96,9
	31		976	14.1	LF	$3.27	$1.90M	$120,553	$346,501	100							

OK Cancel

Fig. 8 NPC for diesel price of $0.56/1 for System configuration for Wilberforce island

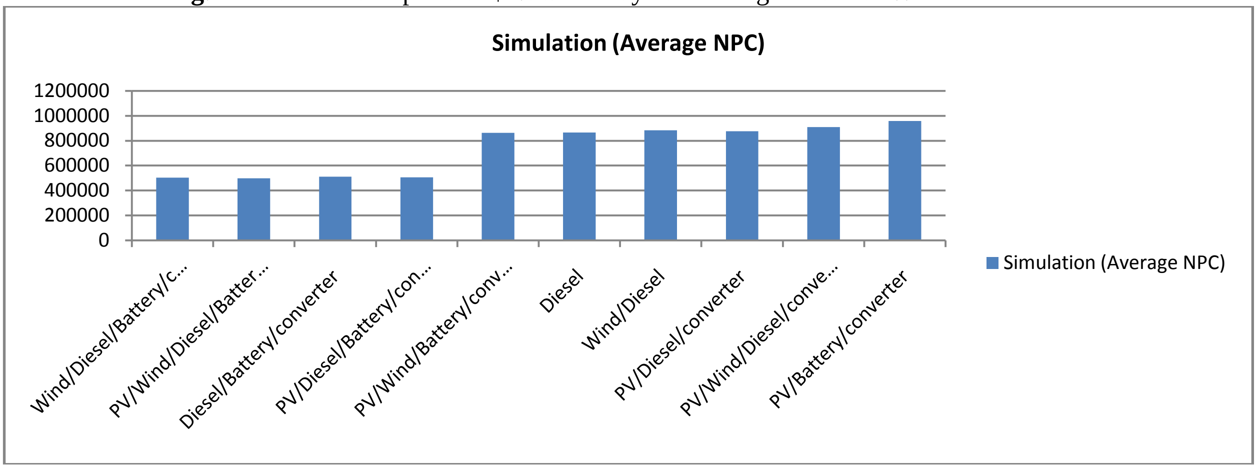


Fig. 9 NPC for diesel price of $0.56/1 for 10 System configurations

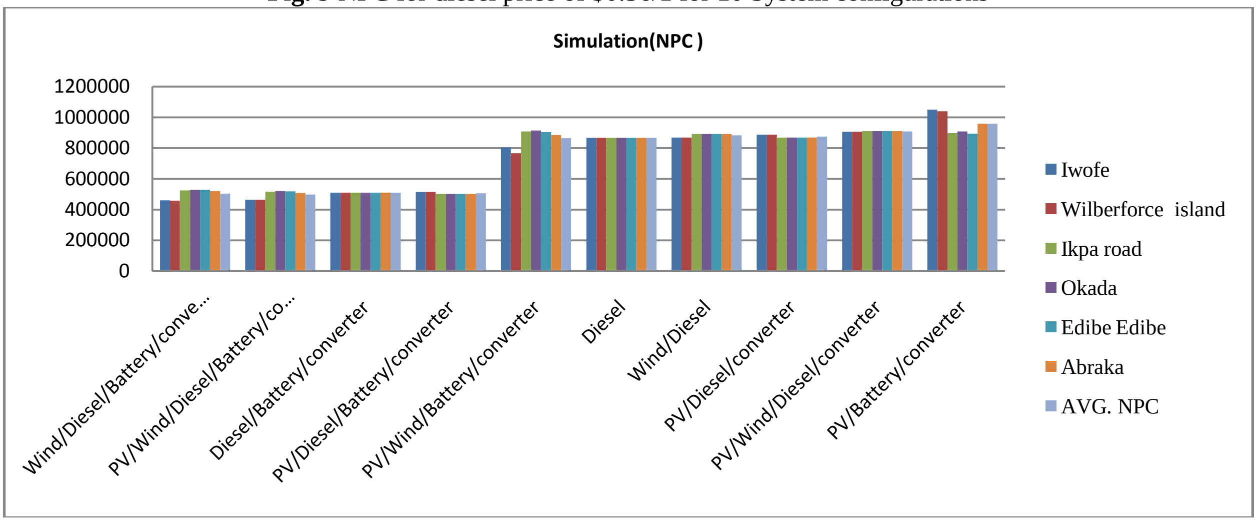


Fig. 10 NPC for all location and 10 system configurations

From the NPC analysis, it can be observed that stand-alone PV/Wind/diesel/battery/ converter system has the lowest NPC among the studied configuration for all the location when considering the average total NPC of each configuration in table 4. This study will be comparison will be mostly on Hybrid PV/Wind / Diesel/ Battery/ Converter system configuration. The wind system is not the best option because of the low wind speed at most of the sites. Fig. 11 and 12 show the graphical representation of NPC and COE respectively for PV/Wind/diesel/battery systems for all sites. In all the case of NPC calculation, $1 ₦356, where $ is US Dollars and ₦ is Nigerian currency in Naira. The lowest 'NPC is obtained in Wilberforce Island, found in the tropical monsoon climatic zone. At $0.56/L, the NPC is $464240 and COE is $1.03/kwh. The result shows the direct relationship between NPC and the level of components resources(solar radiation and wind speed), The higher the solar radiation in a site, the lower will be the NPC value, The higher the wind speed in a site, the lower will be the NPC value, This is because high irradiation will enable the PV system to supply the

load for a longer period, thereby reducing the operating hours of the diesel generator; this will bring about reduction in the diesel consumption and cost associated with diesel, which thus relates directly to low NPC.
Iwofe in the tropical wet climate is next to Wilberforce Island with value of $464248, followed by Abraka which stands at $507588NPC. The difference in average solar radiation and wind speed between these sites is found to be minimal. Okada, which represents the tropical climate, showed the highest NPC out of the six sites considered in the simulation. This is attributable to the low average daily global wind speed as found in this site compared to Wilberforce Island and Iwofe daily wind speed. The total NPC of Okada is $519876; when compared to the base case NPC (i.e. diesel generator only), a saving of $347050can be achieved.

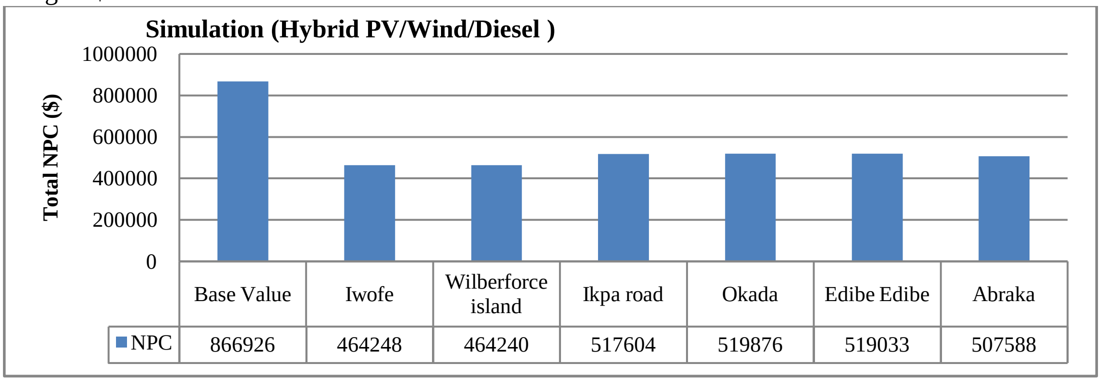


Fig. 11 Graphical representation of NPC for Hybrid PV/Wind/Diesel/Battery system

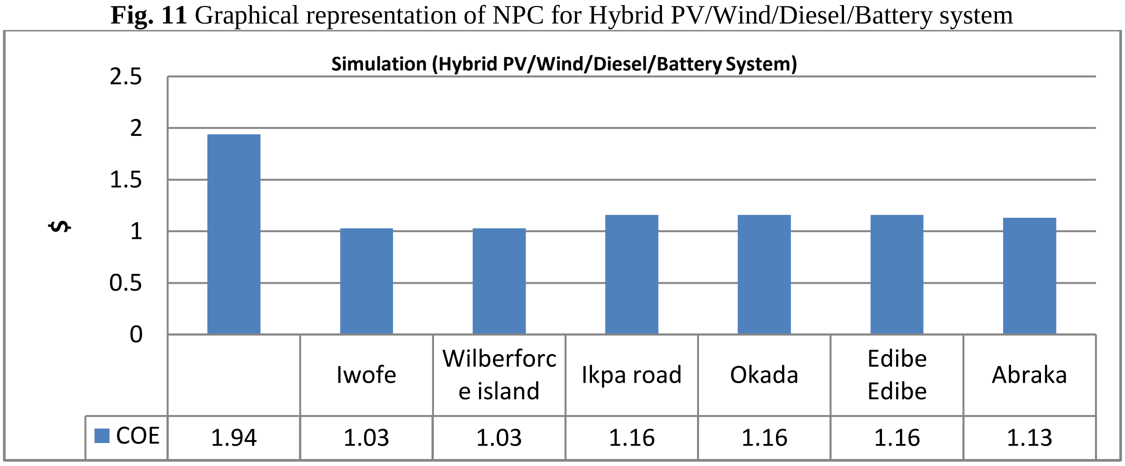


Fig. 12 Graphical representation of COE for Hybrid Power System

System Architecture

Table 5 presents the number of components selected for most feasible configuration (PV/Wind/diesel/battery) in each state in south geopolitical zone of Nigeria, based on $0.56/L diesel price considered. HOMER considered many factor such as global solar irradiation, global wind speed, diesel prices as well as load profile in coming up with this optimized number of system components. The component optimization process prioritizes continuous meeting of load demands by the hybrid system. This is aimed at ensuring marginal diesel consumption as well as making sure that PV system and wind turbine is not oversized. The space requirement for installation is also considered in the sizing of the batteries component.

Table -5 System Architecture for Calculations for Hybrid Pv/wind/diesel/battery/converter

Sensitivity case	Villages		
	$0.56/L		
	Abraka	**Ikpa road**	**Wilberforce**
PV array (kw)	10.8	11.2	0.590
Generator (kw)	17	17	17
Wind turbine (kw)	1	1	4
Converter (kw)	13.8	12.2	10.5
Number of batteries	80	80	64
	Okada	**Iwofe**	**EdibeEdibe**
PV array (kw)	11.2	1.89	11.9
Generator (kw)	17	17	17
Wind turbine (kw)	1	4	1
Converter (kw)	13.2	12.2	11.4
Number of batteries	88	72	88

The smallest component sizing in system architecture was obtained at Wilberforce Islandout of all the sites considered. The system architecture includes 0.59 kW solar panel, a 17 kW generator, a 10.5 kW converter and 64 batteries. It was noted from the simulation that most of the sites considered except EdibeEdibe, reported increase in the size of PV panel and batteries bank. This justifies the extra costs of installing a larger PV array and increasing the storage capabilities of the system in order to minimize the operating hours of the generator, thus keeping the NPC as low as possible.

RF Calculations

Renewable fraction varies as the system architectures for each site considered in the simulation. It can be observed from (Fig. 13) that RF for each site in the simulation is notably high for sensitivity case of \$0.56/1.Out of the six sites considered, Iwofe, Wilberforce and EdibeEdibe experience highRF value, the values are 0.29,0.26,0.22at \$0.56/L respectively. The lowest RF of 0.19 occurs in Okada for sensitivity case of \$0.56/I. Ikpa road and Abraka also experience a relatively low RF of 0.20 and 0.21 respectively for diesel price of \$0.56/1.

Carbon Emissions and Diesel Consumption

Annual CO_2 emissions relate directly to the amount of litres fuel consumed by the diesel generator per year. Fig. 14 shows a comparison to the total amount of diesel consumed per year by PV/diesel/battery configuration for each site with base case simulation at diesel price \$0.56/1.

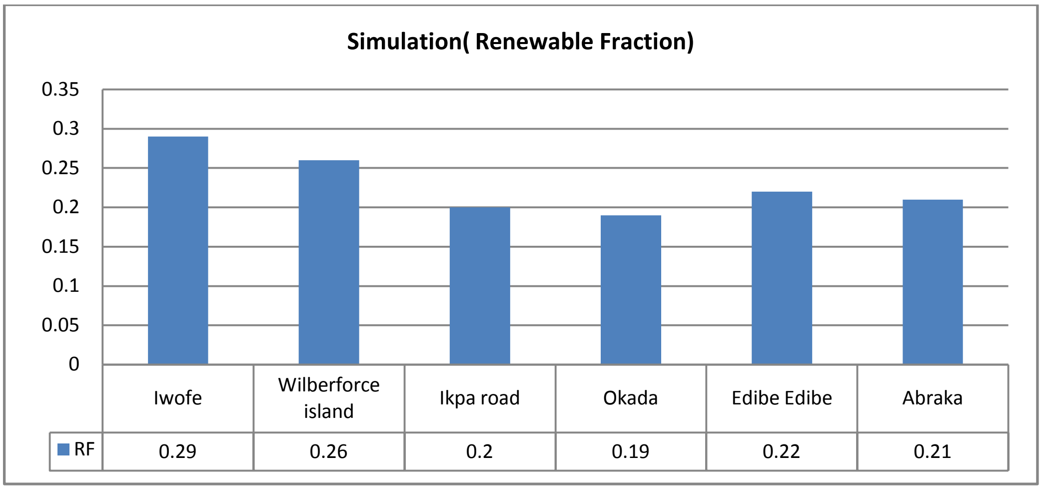


Fig. 13 RF for diesel price of \$0.56

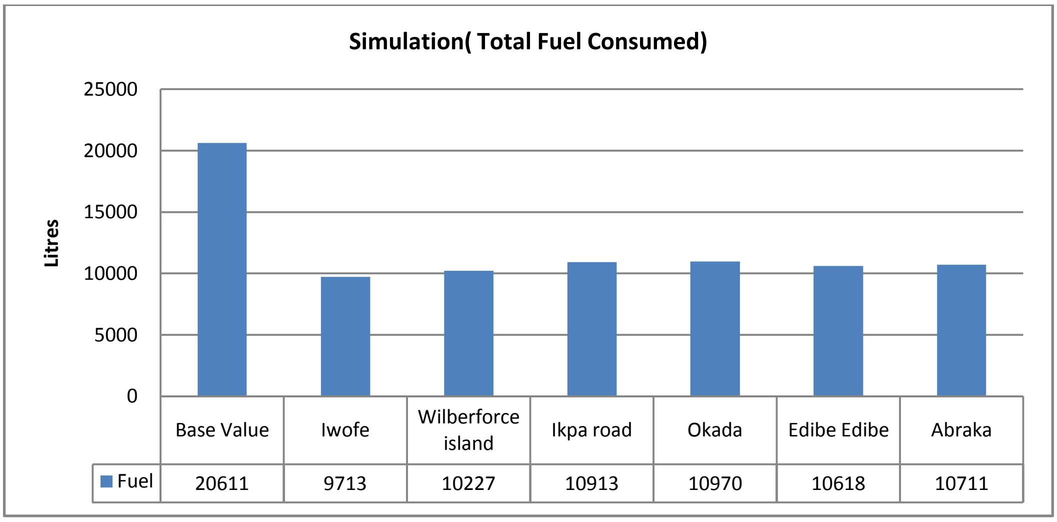


Fig. 14 Diesel consumption ((L) for diesel price of \$0.56.

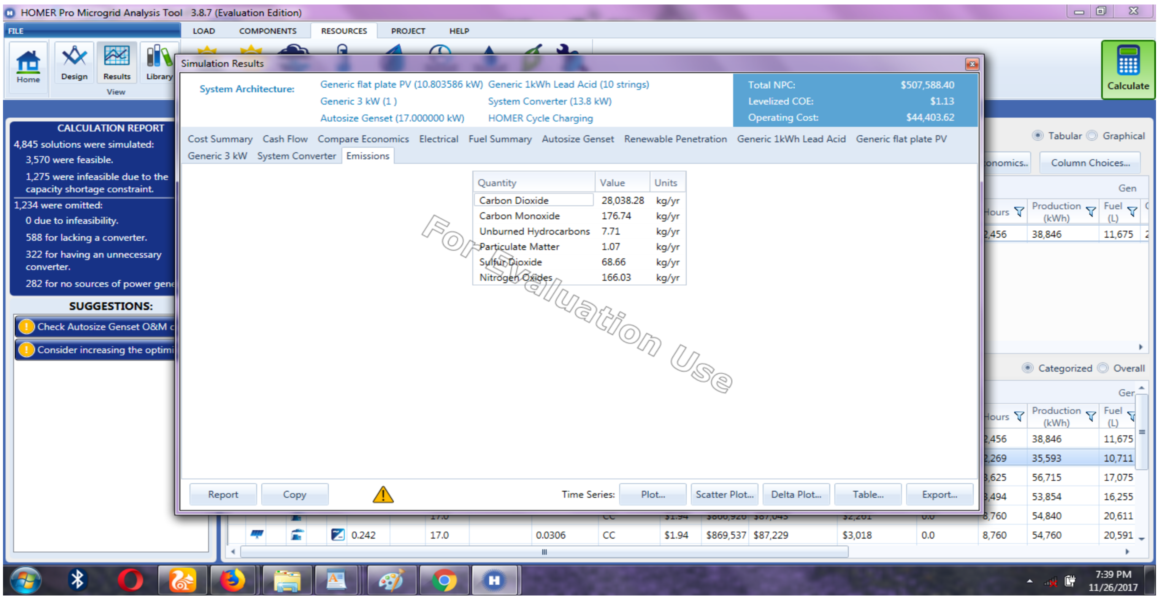


Fig. 15 CO_2 Emission (kg/yr) for diesel price of $0.56/1 for Abraka

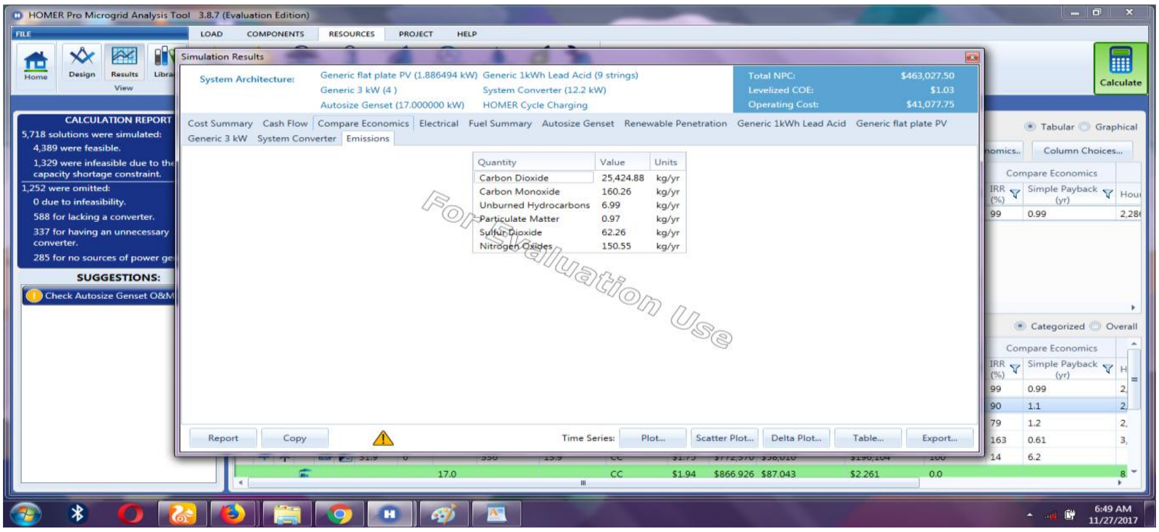


Fig. 16 CO_2Emission (kg/yr) for diesel price of $0.56/1 for Iwofe

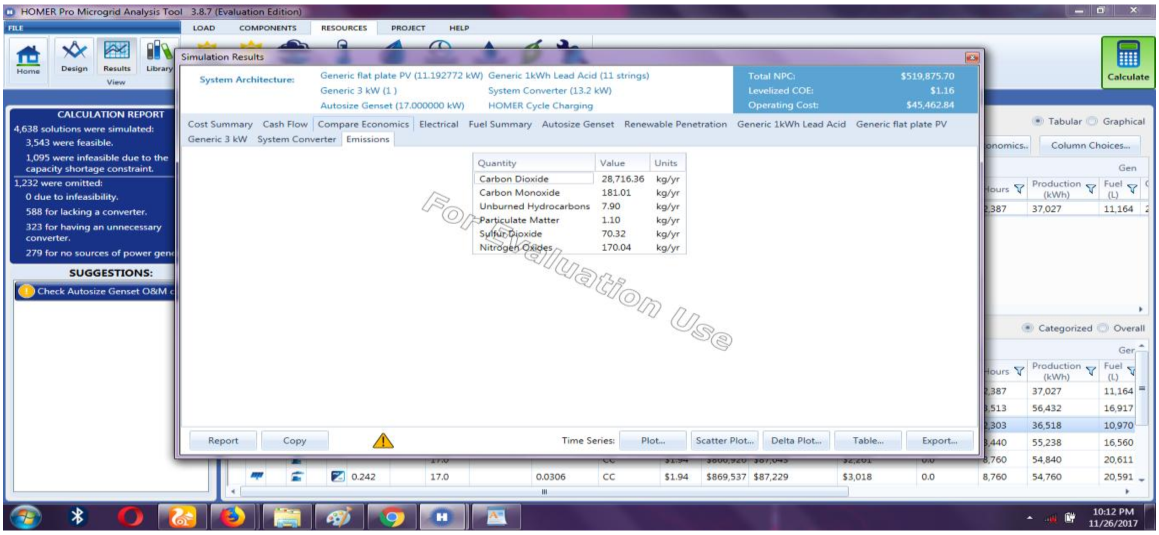


Fig. 17 CO_2Emission (kg/yr) for diesel price of $0.56/1 for Okada

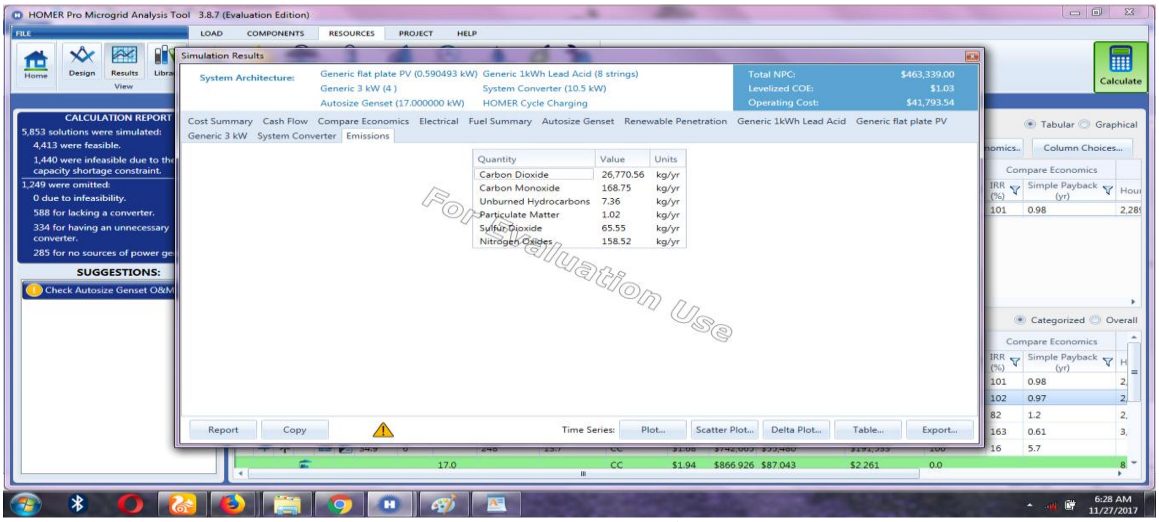


Fig. 18 CO_2Emission (kg/yr) for diesel price of $0.56/1 for Wilberforce island

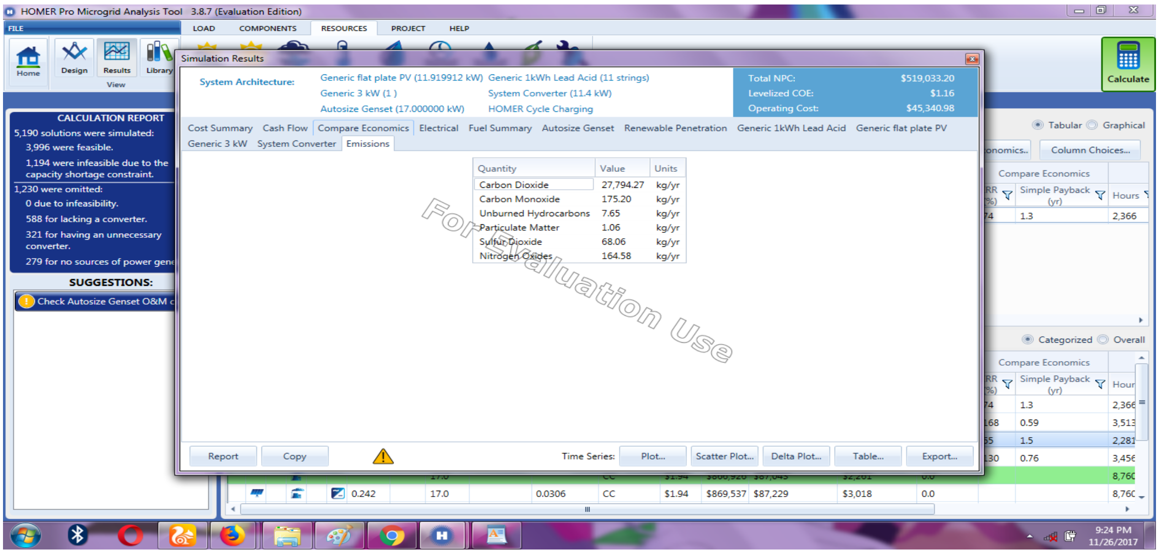


Fig. 19 CO_2 Emission (kg/yr) for diesel price of $0.56/1 for EdibeEdibe

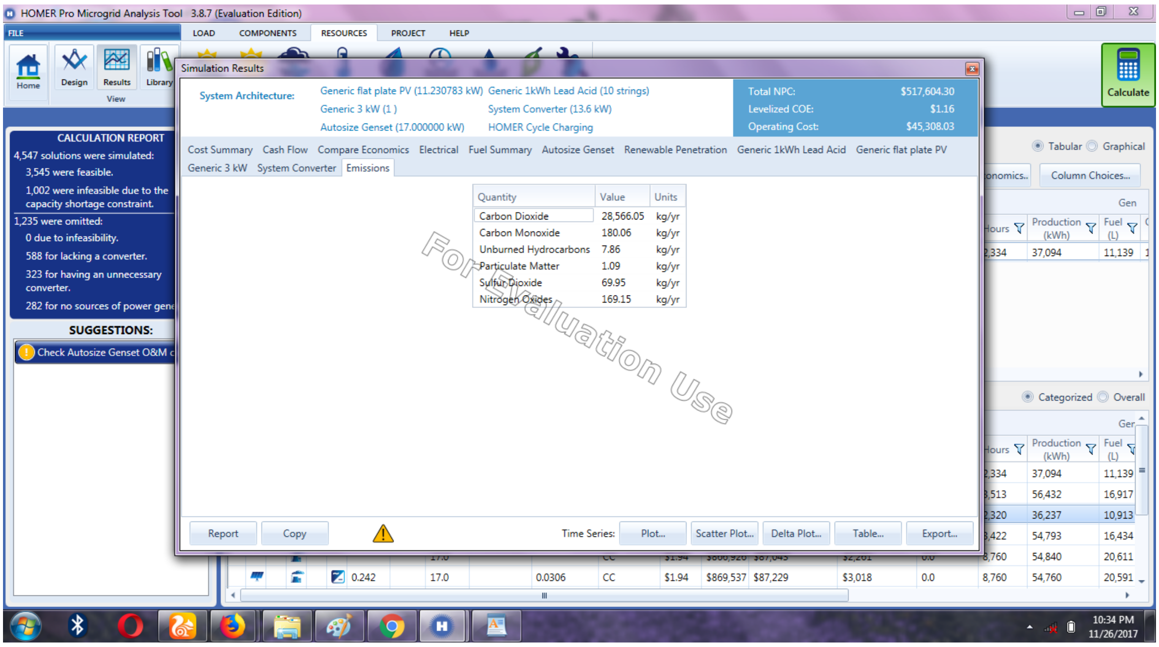


Fig. 20 CO_2 Emission (kg/yr) for diesel price of $0.56/1 for Ikpa road

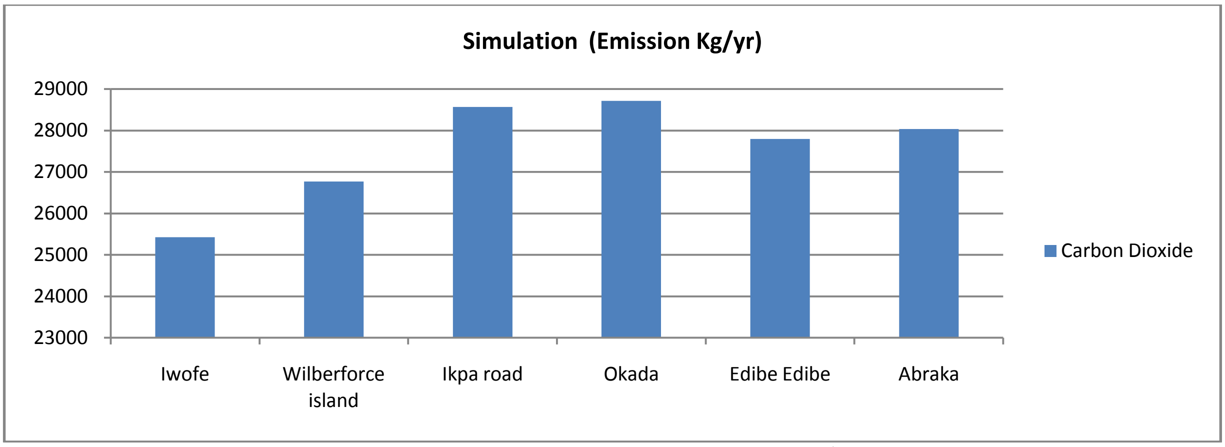


Fig. 21 CO_2 Emission (kg/yr) for diesel price of $0.56/1.

CO_2 Emissions in kg/yr for the sensitivity cases at each site are shown in – Iwofesite consumed the least volume of diesel per year (9713L at diesel price $0.56/I), while the highest volume of diesel consumption is observed at Okada. Comparing Fig 14 and Fig. 21: It shows that the hybrid renewable energy system configuration, provide a greater savings in CO_2 emission as the lower the volume of fuel consumed, the lower the CO_2emitted (diesel generator system). Iwofe displays the lowest amount of CO_2 emission (25424.88 kg/yr). Followed by Wilber force island (26770.56 kg/yr) .The highest value of CO_2 emissions occurred at Okada, which stands at 28716.36 kg/yr for the sensitivity case of $0.56 /1.

Table -6 Electrical Summary of hybrid Pv/wind/diesel/battery/converter systems

Electrical	Abraka	EdibeEdibe	Okada	Ikpa road	Wilberforce island	Iwofe
Generic flat plate PV(kWh/yr)	16704	18417	17299	17351	911	2907
AutosizeGenset(kWh/yr)	35593	35184	36518	36237	33245	31982
Generic 3Kw(kWh/yr)	2550	1217	4133	1414	21532	21066
Total(kWh/yr)	54847	54818	54950	55002	55688	55955
AC Primary load (kWh/yr)	45092	45092	45092	45092	45092	45092
Excess Electricity	210.9	175.9	84.1	178.5	2310.9	2172.6
Renewable Fraction	21.1	22	19	19.6	26.3	29.1

Wilberforce Island has the highest excess electricity of 2310.9kWh/yr which is 4.1% of total production as shown in table 7 while Iwofefollows as second highest with excess electricity of 2172.6kWh/yr which is 3.9% of total production while Okada has lowest excess electricity quantity of 84.1kWh/yr which is 0.2% of total production. The total Ac primary load for all the location is same having 45092kWh/yr consumption.

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